



US 20050195761A1

(19) **United States**(12) **Patent Application Publication** (10) **Pub. No.: US 2005/0195761 A1**
(43) **Pub. Date: Sep. 8, 2005**(54) **METHOD FOR LOCATION TRACKING
USING VICINITIES****Publication Classification**(76) Inventors: **Mansoor Ali Khan Alicherry**, Scotch
Plains, NJ (US); **Harsha S. Nagesh**,
Berkeley Heights, NJ (US); **Chitra A.**
Phadke, Basking Ridge, NJ (US);
Viswanath Poosala, Middlesex (IN)(51) **Int. Cl.⁷** **H04Q 7/00**(52) **U.S. Cl.** **370/328; 370/312**Correspondence Address:
Docket Administrator
(Room 3J-219)
Lucent Technologies Inc.
101 Crawfords Corner Road
Holmdel, NJ 07733-3030 (US)(57) **ABSTRACT**

A method for location tracking on a distributed basis using multiple locations, which utilizes a pairwise application of distance constraints and vicinities for determining locations. The location of a particular node is represented by a group of points (as opposed to a single point) defined by the vicinity.

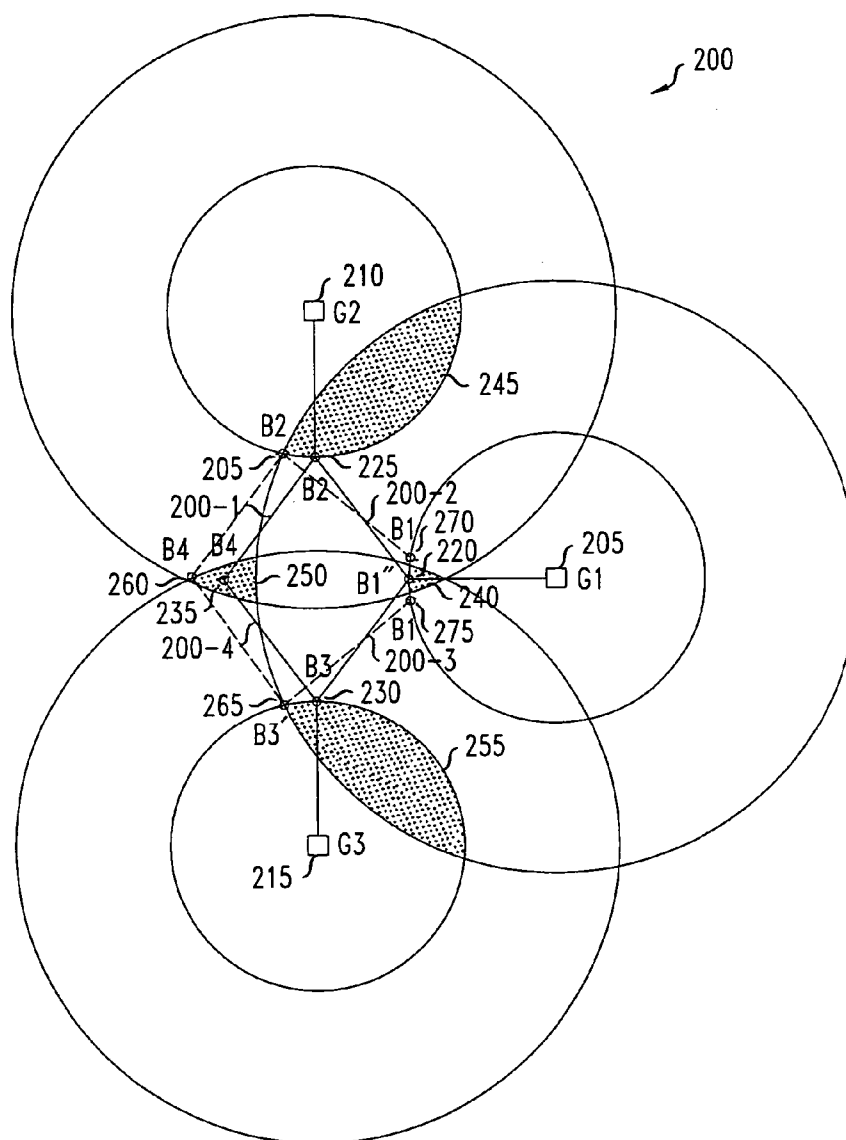
(21) Appl. No.: **10/795,606**(22) Filed: **Mar. 8, 2004**

FIG. 1

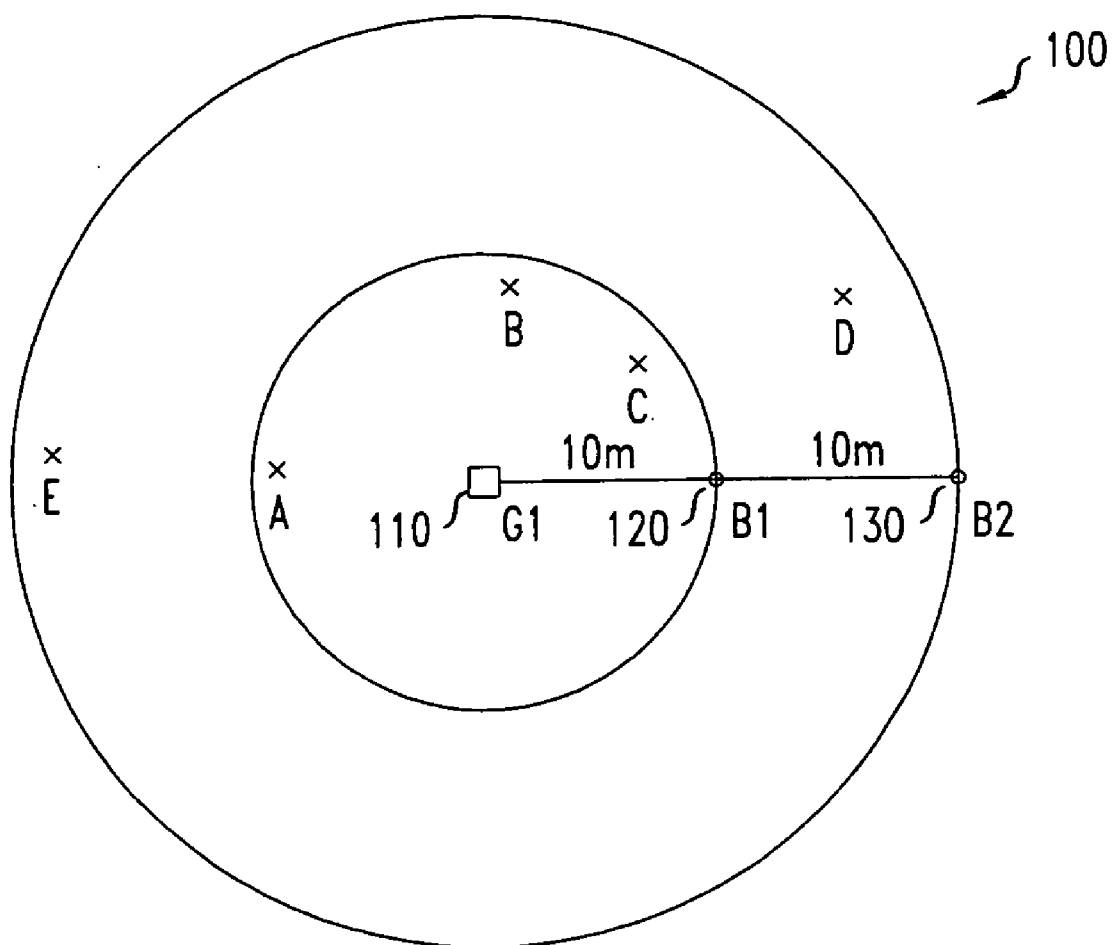


FIG. 2

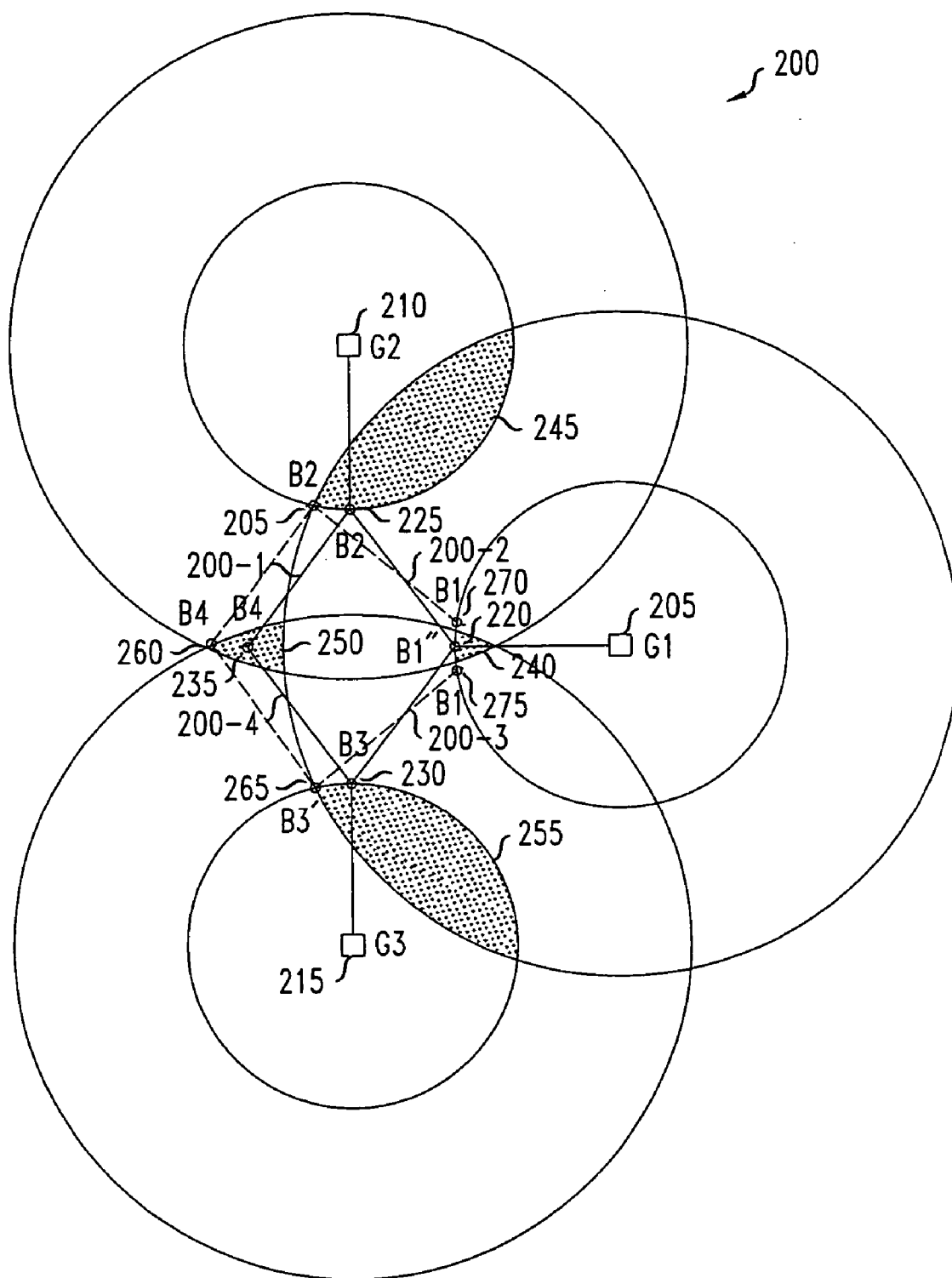


FIG. 3

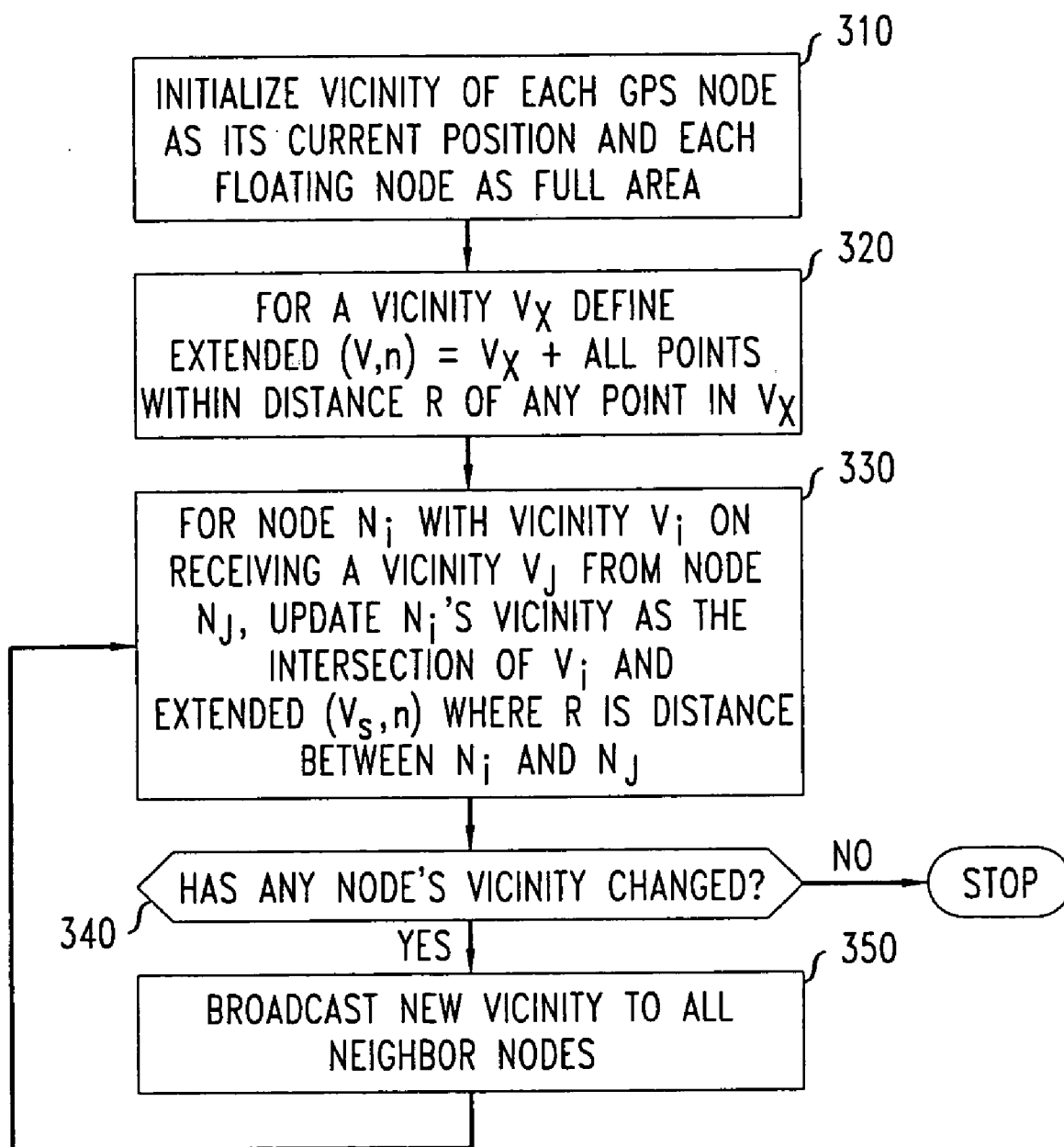


FIG. 4

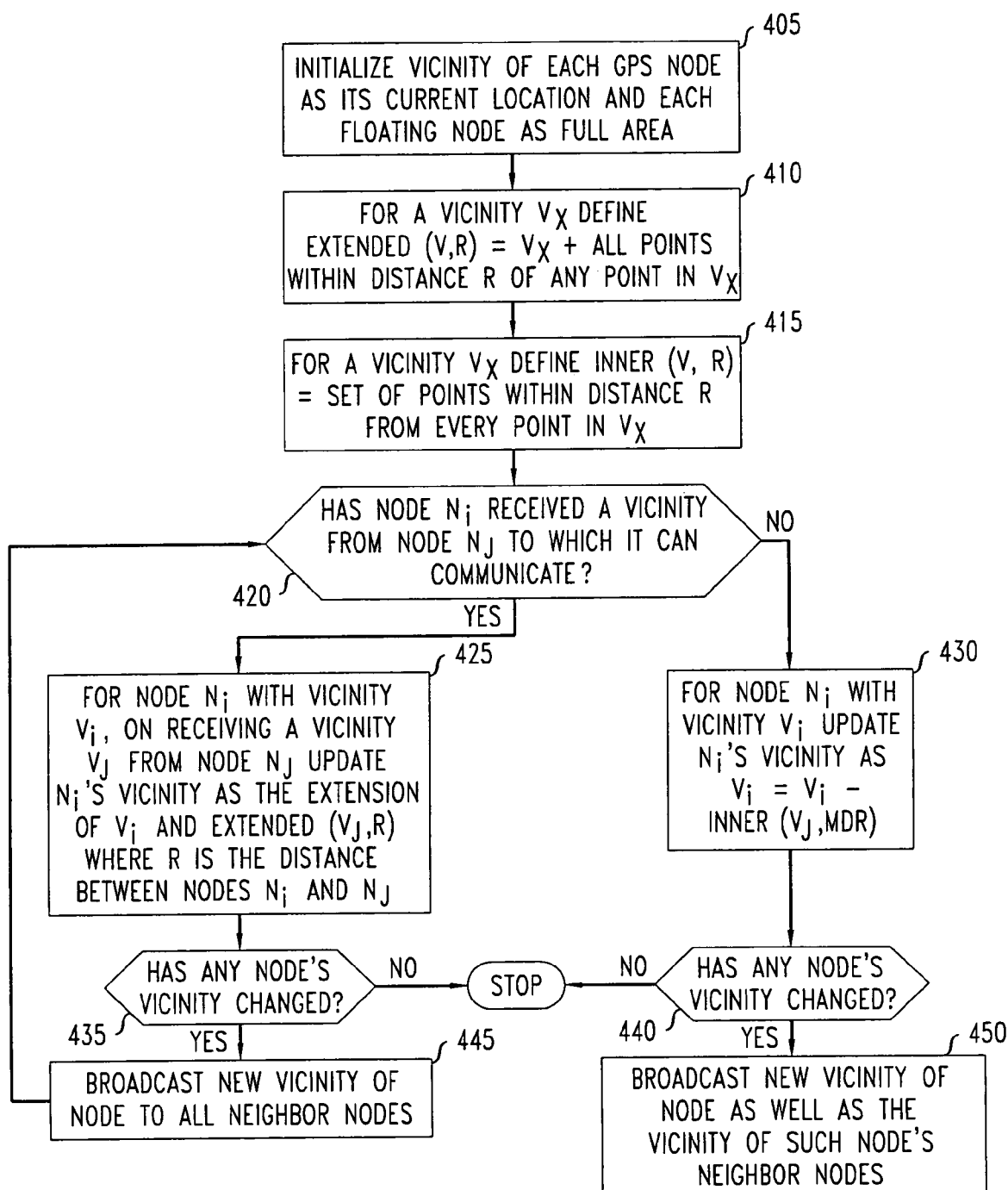
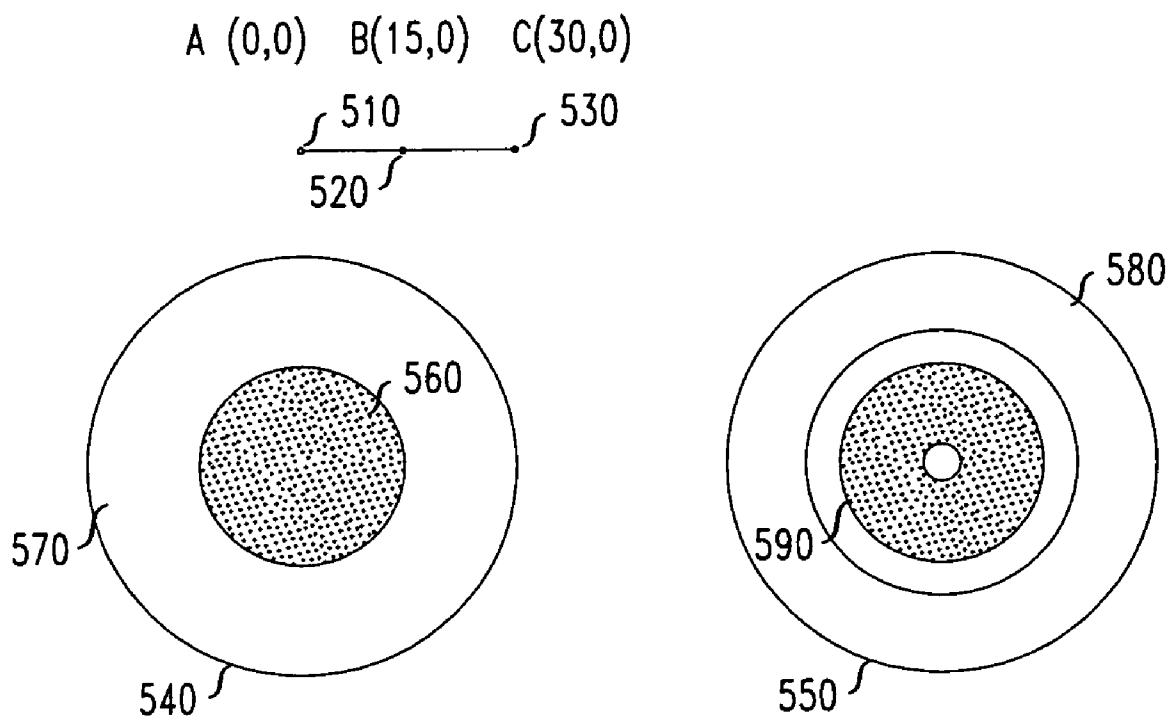


FIG. 5



METHOD FOR LOCATION TRACKING USING VICINITIES

FIELD OF THE INVENTION

[0001] The present invention relates generally to location tracking and, more particularly, to a method for tracking the locations of devices in communications networks such as cellular and ad hoc communications networks.

BACKGROUND OF THE INVENTION

[0002] Wireless cellular telecommunications systems, wire-line telecommunications systems, and the Internet are well-known examples of so-called fixed infrastructure networks. These types of networks are characterized in part by their use of a fixed infrastructure (e.g., wireless base stations, central offices, local loops, routers and the like) and the ability to leverage a known network topology (e.g., in making routing decisions among network nodes). Despite their many advantages, such fixed networks can be expensive to upgrade and can be uneconomical where the number of users is minimal (see, for example, J. Li et al., "A Scalable Location Service for Geographic Ad Hoc Routing", *Proceedings ACM/IEEE Mobicom*, pp. 120-130, August 2000, which is hereby incorporated by reference). In contrast, well-known ad hoc networks do not utilize a fixed infrastructure instead utilizing a variable infrastructure which changes as a function of the devices coming together to form the particular ad hoc network. As will be appreciated, ad hoc networks offer increased flexibility and decreased fixed investments to implement (see, for example, Li et al., supra).

[0003] An important application in either fixed infrastructure networks or ad hoc networks is so-called "location tracking" which is the ability to locate particular devices (e.g., a node) throughout the network. Location tracking arises in several contexts in mobile networking. For example, location-based routing algorithms have been proposed to reduce the amount of data transferred in computing a path in ad hoc networks (see, for example, Y. B. Ko et al., "Location-Aided Routing (LAR) in Mobile Ad hoc Networks", *Proceedings ACM/IEEE Mobicom*, pp. 66-75, October 1998, which is hereby incorporated by reference). Further, well-known cellular applications such as fleet tracking and emergency response systems rely on location information in delivering their respective cellular services. As such, the accuracy of the location information is central to the performance of all these applications whether being delivered via a fixed network or ad hoc network.

[0004] There exist a number of well-known location tracking techniques. For example, triangulation is the well-known technique of locating a particular mobile device through the knowledge of the angle of arrival of signals at the to-be-located mobile device from three other devices, where the locations of the three other devices are known. Trilateration is the well-known technique of locating a particular mobile device by determining the distance of the to-be-located mobile device from at least three reference points whose precise location is known. For example, the three reference points might be three other mobile devices in proximity to the to-be-located mobile device. In terms of locating a cellular telephone, two primary forms of trilateration are used in conventional, cellular communications. The first form of trilateration is performed by the cellular network

itself using its network infrastructure; in particular, the network uses the known locations of each base station within its infrastructure to locate a particular mobile telephone. Specifically, the location of three known base stations in the same geographic location as the to-be-located mobile telephone is used to determine the relative position of such device. The typical locating precision of this technique is approximately in the range of 50 meters to 300 meters.

[0005] The second trilateration form conventionally used in locating a particular mobile telephone device within the cellular communications network employs the well-known Global Positioning System (GPS). GPS is a time-synchronized, space-based satellite system that broadcasts spread spectrum codes and consists of a GPS constellation consisting of 24 individual satellites. A ground-based GPS receiver at or near the object to be located (e.g., the cellular telephone device) determines the difference between the time at which each satellite transmits a particular time signal and the time at which such signal is received. Using the calculated time differentials in standard GPS, the object's location is determined typically to within about 100 meters. This accuracy can be further improved upon by using the well-known commercially available Differential GPS, which improves the GPS location accuracy to within 10 meters.

[0006] Still other techniques have been proposed for locating mobile devices in the contexts of indoor ad hoc networks. For example, RADAR (see, P. Bahl et al., "RADAR: An In-Building RF-Based User Location and Tracking System", *IEEE Info Com*, March 2000, which is hereby incorporated by reference) is a well-known technique for tracking indoor environments where a single fingerprint of an entire region is constructed and the location of a particular node is determined based on the signal strength observed at its location. Further, for example, CRICKET (see, N. B. Priy-antha et al., "The CRICKET Location-Support System", *ACM MOBICOM*, August 2000, which is hereby incorporated for reference) is another well-known indoor tracking technique where nodes have so-called "listeners" which receive periodic radio and ultrasound signals from base stations in a network. Thereafter, such signals are employed to determine a particular node's location using an estimate of such node's proximity to the base stations. In CRICKET, the objective is to make an association with the closest base station and not to precisely estimate the true position of the mobile node.

[0007] In addition to the above-mentioned RADAR and CRICKET techniques, LAR is a reactive routing protocol used in mobile ad hoc networks where all the nodes are aware of their respective locations, see, for example, Y. B. Ko et al., supra. In LAR, the source of a packet session initiates a route request for the destination. This request, in turn, is forwarded by other nodes that lie within a so-called "request region", such request region being computed by the source from the previous known location and velocity of the destination. In the event that a route reply is not received within a specified timeout, LAR either resorts to a global flooding protocol or gradually expands the request region and repeats the discovery process until the route is computed.

[0008] Geographic forwarding is a stateless packet forwarding technique employed in large wireless networks, see,

for example, J. Li et al., supra; and C. T. Cheng et al., "SLALOM: A Scalable Location Management Scheme for Large Scale Mobile Ad hoc Networks", *Proceedings of Wireless Communications and Networking Conference*, March 2002, which is hereby incorporated by reference. In geographic forwarding, nodes are aware of their respective locations and a packet intended for a destination is forwarded to the destination's location by the intermediate nodes. The intermediate nodes forward the packet to a neighbor node that is determined to be the closest to the destination in terms of a Euclidean distance.

[0009] Other location-based techniques include using short-range, peer-to-peer communications in combination with the imposition of particular distance constraints between nodes to identify a location of a particular node (see, for example, L. Doherty, "Algorithms for Position and Data Recovery in Wireless Sensor Networks", *Master's Report, University of California Berkeley*, June 2000, which is hereby incorporated by reference). However, Doherty's technique is best suited for centralized execution which presents certain challenges in a distributed network. Another technique detailed in D. Niculescu et al., "Ad hoc Positioning System (APS) Using AOA", *IEEE Infocom*, April 2003, which is hereby incorporated by reference, is directed to a node measuring the angle of arrival of signals from various points (where such points have knowledge about their respective locations) and using triangulation to determine the node's location.

[0010] As described above, there exist numerous location-based routing and location information techniques employed in wireless or ad hoc communications networks. Central to the above-described techniques, however, is that they primarily attempt to compute a single point location, which may or may not be the true location. Obviously, if the computed single location is incorrect, that information will adversely impact network performance (e.g., data will be forwarded to incorrect nodes, or data may take extended paths leading to dropped packets). Further, such techniques are primarily directed to centralized execution as opposed to a more distributed execution.

[0011] Thus, there exists a need for an enhanced location-based routing technique which addresses multiple locations and provides for distributed execution.

SUMMARY OF THE INVENTION

[0012] The present invention provides a method for location tracking on a distributed basis using multiple locations. More particularly, in accordance with an aspect the invention, a pairwise application of distance constraints utilizes so-called vicinities for determining locations. In accordance with an aspect of the invention, vicinities are determined, and used in location tracking, as a function of proximity constraints only. In accordance with an embodiment of the invention, the vicinities of each node in the communications network are initialized as follows: (a) the vicinity of a fixed node (e.g., GPS node) is defined as its current location; and (b) the vicinity of each floating node (e.g., a cellular telephone) is defined as its entire region or full area (i.e., since such floating nodes do not have knowledge of their location at initialization). Further, in accordance with the invention, for a given vicinity V_x an extended vicinity is defined as the points in the given vicinity combined with the points within

a distance R of any point in V_x . Thus, for each node N_i with vicinity V_i , upon such node receiving a broadcast of vicinity V_j from node N_j , the vicinity of N_i is updated as the intersection of V_i and the extended vicinity(V_j, R), where R is the distance between node N_i and node N_j . As the vicinity of a node changes such node will broadcast it's updated vicinity to the other neighboring nodes. The vicinity updating continues until such time that the vicinities associated with the respective nodes stop shrinking (i.e., stops reducing in the number of locations within a particular vicinity). In accordance with the various aspects of the invention, the location of a particular node is represented by a group of points (as opposed to a single point) defined by the vicinity.

[0013] In accordance with a further aspect of the invention, vicinities are determined, and used in location tracking, as a function of both proximity constraints and non-proximity constraints, in a communications network in accordance with the aspects of the present invention. More particularly, in accordance with this further aspect of the invention, if node N_i is unable to communicate with N_j it can be concluded that node N_i is not within a circle of radius mdr of N_j . Thus, if N_i is a floating node then N_i cannot be at any point within a maximum distance range as defined by the particular transmission device (hereinafter referred to as "mdr") from every point in N_j 's current vicinity. Therefore, points can be eliminated from N_j 's vicinity that do satisfy such a requirement. Again, the location of the particular node, in accordance with the aspects of the invention, is represented by a group of points (as opposed to a single point) defined by the vicinity.

[0014] Advantageously, in accordance with the invention, each node has a vicinity, at any point in time, which may be utilized in location tracking and routing in the communications network. Importantly, in accordance with the invention, the location of a particular node is represented by a group of points (as opposed to a single point) defined by the vicinity thereby minimizing the adverse impact of location errors (i.e., as in the single point location techniques) and allowing for a distributed solution. More particularly, the distributed advantage of the invention stems from the fact that each node determines and updates its location (through vicinities) utilizing information local to such node thereby eliminating the need to communicate with a central server for such purposes.

BRIEF DESCRIPTION OF THE DRAWINGS

[0015] FIG. 1 shows an illustration of proximity and non-proximity distance constraints;

[0016] FIG. 2 shows the pairwise application of the distance constraints of FIG. 1 in accordance with the principles of the invention;

[0017] FIG. 3 shows a flowchart of illustrative operations for determining vicinities, as a function of proximity constraints only, in a communications network in accordance with the principles of the present invention;

[0018] FIG. 4 shows a flowchart of illustrative operations for determining vicinities, as a function of both proximity constraints and non-proximity constraints, in a communications network in accordance with the principles of the present invention; and

[0019] FIG. 5 shows an illustrative location tracking example utilizing the illustrative operations of FIG. 3 and FIG. 4 for determining vicinities in accordance with the principles of the invention.

DETAILED DESCRIPTION

[0020] The present invention provides a method for location tracking on a distributed basis using multiple locations. To facilitate the understanding of the present invention several terms will first be introduced and discussed in some detail. In accordance with an aspect of the invention, a so-called “vicinity” is defined as the area containing an actual location (e.g., a node). More particularly, as used throughout this disclosure, a vicinity is defined as:

[0021] (1) Vicinity. Let n_i be a node in a network in a region R. Then, the vicinity V of n_i is any subset of points in R that contains the actual location of that particular node.

[0022] A vicinity, in accordance with the invention, can be a disconnected set of points (i.e., not contiguous points or regions of points) or a bounded area (i.e., contiguous points or regions of points) ranging from a node’s exact location to an entire cell area. Further, as used throughout this disclosure, a so-called “feasible vicinity” is a specific vicinity which comprises the locations of a particular node which are present in the so-called “feasible solution set” for a given constraint set. As used throughout this disclosure, a “feasible solution” is defined as:

[0023] (2) Feasible Location & Feasible Solution. For a given class(es) of constraints, a feasible solution is any location vector of the nodes ($[l_1, l_2 \dots l_n]$) that satisfies all of those constraints. In addition, a “feasible set” is the set of all possible feasible solutions.

[0024] Thus, for every element in a feasible vicinity there exists a positioning of the other nodes such that the constraints are satisfied. In terms of applying the constraints, as will be appreciated, distance constraints can be defined such that at any given instant a specific distance relationship will hold between each pair of nodes in a network. Two such distance constraints are as follows:

[0025] (3) Proximity—If two nodes (n_i, n_j) can communicate using so-called static radios (i.e., a device can only transmit at a maximum distance range of mdr) they are within a distance of mdr of each other. If they can communicate using dynamic radios (i.e., a device can modify its power to change its transmission range from zero to mdr) where the adjustable distance is defined as d, they are within d of each other. Let $\text{dist}(a,b)$ return the Euclidian distance between two locations a and b. Then,

$\text{dist}(n_i, n_j) \leq x$, where $x=d$ for dynamic radios and mdr for static radios.

[0026] (4) Non-proximity—If two nodes (n_i, n_j) cannot communicate with each other, they are more than mdr away from each other. Then,

$\text{dist}(n_i, n_j) > \text{mdr}$.

[0027] As will be appreciated, using the proximity and non-proximity relationships as set forth above, a proximity graph can be constructed with a vertex corresponding to

each node in the a given network and an edge between (n_i, n_j) when they are in proximity (in accordance with definition (3) above).

[0028] For example, FIG. 1 shows an illustration of proximity and non-proximity distance constraints. More particularly, FIG. 1 shows a network 100 consisting of GPS node G_1 110 and two floating nodes B_1 120 and B_2 130, each such floating node containing a dynamic radio (see definition (3) above) and where the exact location of each node is identified in FIG. 1 by their respective node names. In FIG. 1, the maximum range is illustratively set at 15 m which, in turn, provides for node B_1 120 communicating with the other two nodes (i.e., G_1 110 and B_2 130) while B_2 can communicate only with B_1 . Applying a proximity constraint between B_1, G_1 it can be shown that B_1 ’s location can only be inside a circle of radius 10 m from G_1 . Thus, applying the same proximity constraint between B_1, B_2 it can be shown that B_1 must be within a band of 10 m around B_1 ’s possible location which reduces to a circle of 20 m radius around G_1 . Therefore, vector $[G_1, C, B]$ and $[G_1, C, D]$ are two possible feasible solutions. Similarly, by applying the non-proximity constraint between G_1 and B_2 it can be shown that B_2 cannot be within a circle of 15 m around G_1 . In such case, vector $[G_1, C, B]$ is not a feasible solution whereas $[G_1, C, D]$ is feasible.

[0029] Existing location tracking techniques (as described previously) can be generally classified as computing a single feasible solution under proximity constraints (i.e., a so-called “single point solution”). As such, all feasible solutions are equally valid under a given set of constraints such that there exists no guarantee that the chosen solution is closer to the actual location than any other possible location. In such single point solutions, the locations used are a function of a feasible solution computed under a set of constraints. That is, this type of solution is essentially a randomly chosen element of the feasible set. As long as the nodes have not moved, the same locations are used at each invocation to compute distances, path lengths and the like. As a result, if the particular chosen feasible solution is incorrect, the entire network’s (or location system) performance is adversely affected.

[0030] To address the above, the Applicants herein have realized an improved location tracking technique which, in accordance with the various aspects of the present invention, utilizes multiple feasible solutions such that a randomly chosen feasible solution is employed for each invocation. More particularly, in accordance with an aspect of the invention, multiple location vectors (i.e., multiple feasible solutions are selected on a random basis from the vicinities of other nodes) that are valid under a given set of inter-node distance constraints are utilized for locating a particular location (e.g., a node) in a distributed (as opposed to centralized) fashion.

[0031] As introduced above, in accordance with an aspect of the invention, distance constraints are applied to pairs of nodes for computing supersets of feasible vicinities. In particular, given a set of constraints, the vicinities in accordance with this aspect of the invention have the following property:

[0032] (5) Consider a location 1, occurring in the vicinity V_i of a node n_i . When the proximity constraint is used, for every node n_i there exists a

location l_j in the vicinity V_j of n_j such that l_i and l_j are mdr (see definition (3) above). If the non-proximity constraint is used, then for every node n_i that is not a neighbor of n_j , there exists at least one location V_j such that l_i and l_j are more than mdr away (see definition (4) above).

[0033] The aforementioned aspect of the invention related to the pairwise application of constraints (as opposed to applying all the constraints together) is illustrated in **FIG. 2** which shows a region **200** with three GPS nodes (G_1 **205**, G_2 **210** and G_3 **215**), and four floating nodes (B_1 **220**, B_2 **225**, B_3 **230** and B_4 **235**). The edges (**200-1**, **200-2**, **200-3** and **200-4**) connecting the four floating nodes are each, illustratively, 10 m in length. The vicinities (vicinity **240**, **245**, **250** and **255**), in accordance with the invention, of these nodes are shown in the shaded regions of **FIG. 2**. Further, let B_4 '**260** be a location chosen from the vicinity **250** of B_4 **235**. Thus, as shown in **FIG. 2**, B_2 '**205**, and B_3 '**265** are 10 m from B_4 '**260** as determined by applying the principles of the invention. Additionally, the only location in vicinity **240** (i.e., the vicinity of node B_1 **220**) at a distance of 10 m from B_2 '**205** is B_1 '**270**, and from B_3 '**265** is B_1 '**275**. Therefore, given B_1 '**270** and B_1 '**275** are two different points in vicinity **240** there is no feasible solution having B_4 '**260** as the possible position of node B_4 **235**.

[0034] In accordance with the invention, the pairwise application of constraints are used for determining vicinities. The determination and use of such vicinities in location tracking is a further aspect of the invention. To that end, **FIG. 3** shows a flowchart of illustrative operations for determining vicinities, as a function of proximity constraints only, in a communications network in accordance with the principles of the present invention. More particularly, in accordance with this embodiment of the invention, the vicinities of each node in the communications network are initialized (see block **310**) as follows: (a) the vicinity of GPS node is defined as its current location; and (b) the vicinity of each floating node is defined as its entire region or full area (i.e., since such floating nodes do not have knowledge of their location at initialization). Further, in accordance with the invention, for a given vicinity V_x an extended vicinity is defined (see, block **320**) as the points in the given vicinity combined with the points within a distance R of any point in V_x . Thus, for each node N_i with vicinity V_i , upon such node receiving a broadcast of vicinity V_j from node N_j , the vicinity of N_i is updated as the intersection of V_i and the extended vicinity(V_j , R), where R is the distance between node N_i and node N_j (see, block **330**). As the vicinity of a node changes (see, block **340**) such node will broadcast its updated vicinity to the other neighboring nodes (see, block **350**). Such vicinity updating continues until such time that the vicinities associated with the respective nodes stop shrinking (i.e., stops reducing in the number of locations within a particular vicinity). The reductions in locations and their application in bounding a vicinity determination is described in further detail hereinbelow.

[0035] Advantageously, in accordance with the invention, each node has a vicinity, at any point in time, which may be utilized in location tracking and routing in the communications network. Importantly, in accordance with the invention, the location of a particular node is represented by a group of points (as opposed to a single point) defined by the vicinity.

[0036] **FIG. 4** shows a flowchart of illustrative operations for determining vicinities, as a function of both proximity constraints and non-proximity constraints, in a communications network in accordance with the principles of the present invention. More particularly, in accordance with this further embodiment of the invention, if node N_i is unable to communicate with N_j it can be concluded that node N_i is not within a circle of radius mdr of N_j . Thus, if N_j is a floating node then N_i cannot be at any point within mdr from every point in N_j 's current vicinity, therefore, such points can be eliminated from N_i 's vicinity. As shown in **FIG. 4**, initialization (see, block **405**) and defining the extended vicinity function (see, block **410**) occurs in the same fashion as detailed above with regard to the same operations of **FIG. 3**. The operation detailed in block **415** defines a certain inner(V , R) function which is directed to applying the non-proximity constraints in the event certain nodes are unable to communicate as described above. In accordance with this embodiment of the invention, a determination is made (see, block **420**) as to whether a node N_i receives a vicinity from a node N_j to which it can communicate. If so, the application of proximity constraints are applied (see, blocks **425**, **435** and **445**, respectively) in the same manner as these same operations are described above with reference to **FIG. 3**. If such nodes are unable to communicate, non-proximity constraints are applied (see, blocks **430**, **440** and **450**, respectively).

[0037] More particularly, as shown in **FIG. 4**, node N_i 's vicinity is updated (see, block **430**) to remove particular points using the function of inner(V , R). Thereafter, in accordance with this embodiment of the invention, the updated vicinity is broadcast (see, block **450**) together with the vicinities of all the neighboring nodes of N_i . Thus, in accordance with invention, for proximity constraints a node will broadcast only that node's vicinity to the other nodes, and, for non-proximity constraints the node will broadcast the vicinities of its neighboring nodes in addition to its own vicinity.

[0038] **FIG. 5** shows an illustrative location tracking example utilizing vicinities and the illustrative operations of **FIG. 3** and **FIG. 4**. In particular, consider a region (e.g., a region of a wireless communications network) containing three nodes (A, B, C) at locations (0,0), (15,0) and (30,0) respectively (see, nodes **510**, **520** and **530** in **FIG. 5**), where node **510** is a GPS node and nodes **520** and **530** are floating nodes. Further, let the maximum radio range mdr be 20 m. Proximity graph **540** illustrates the results of applying proximity constraints between the three nodes in accordance with the invention. In particular, as shown in proximity graph **540**, node B's vicinity **560** is the set of points within 15 m from node A. Further, the vicinity **570** of node C **530** is the set of points 15 m from the points in node B's vicinity (i.e., a circle of radius **30** around the origin).

[0039] Further, proximity graph **550** shows the results of applying the principles of the invention directed to using both the proximity constraints and non-proximity constraints. In particular, node C **530** cannot communicate with node A **510** so it cannot be within a circle of 20 m around node A **510**. Therefore, in accordance with the invention, node C's vicinity **580** is determined by eliminating points that within 20 m from node A and such vicinity is reduced to the donut-shaped ring of inner radius **20** and outer radius **30** as shown in proximity graph **550**. Interestingly, applying

node C's refined vicinity **580** and the proximity constraints between node B and node C, node B's vicinity is further reduced to contain only points that are within 15 m from any point in node C. Therefore any points within a circle of radius 5 m around the origin are eliminated from node B's vicinity **590** due their failure in satisfying the proximity constraint.

[0040] As will be appreciated from the illustrative example of **FIG. 5**, vicinities are represented as sets of locations, and only when the proximity constraint is enforced is there a guarantee that the vicinities will be of convex (e.g., circular) shape. As will be appreciated, a convex set is a set in which every segment which connects points of the set lies entirely within the set. As will be understood, the vicinities determined in accordance with invention may also be represented using boundaries of shapes by employing well-known computer graphic techniques, or by using a bounding box to approximate the vicinities.

[0041] As will also be understood, the various aspects of the invention described above involve the performance of a significant amount of data transfers and intersections. Therefore, in accordance with an embodiment of the invention, in recognition that certain data transfers lead to an intersection, the data transferred is viewed as the sole complexity metric. That is, in accordance with this embodiment of the invention, the number of data transfers is a measure of the efficiency of the methodology. Therefore, a reduction of the overall amount of data transferred is achieved by utilizing an off-line schedule derived as a function of the proximity graph to dictate when nodes should broadcast their vicinity. To the end, the Applicants herein have derived the following data rate transfer relationships:

[0042] Lemma 1: Consider two neighboring nodes A, B in an acyclic proximity graph whose proximity constraint has already been applied. If the vicinity of one of the nodes is now refined due to external constraints, exactly one intersection is needed to converge the vicinities again.

[0043] Proof 1: Let f_A and f_B denote the vicinities A, B, respectively. Let f'_A denote the newly modified vicinity which is broadcast to B. B computes a new vicinity f'_B by retaining only points that are within mdr of some point in f'_A . Thus, the new vicinity of B will not assist in any further refining of the vicinity of A. Assuming the contrary, let A refine its vicinity to f''_A ($f'_A \subset f''_A$). Consider a location l_A in $f'_A - f''_A$ then by proximity constraint there must be a point l_B in f'_B that is within mdr of l_A , and l_B must be in $f'_B - f''_B$ in order to be removed from f'_A . However, since l_B is within mdr of l_A it would have to be in f''_A , therefore, this contradiction serves as proof that no further refinement of f'_A is possible. Thus, the vicinity refinement process, in accordance with the invention, converges with a single intersection occurring at B.

[0044] Theorem 1: Given a region consisting of n nodes whose proximity graph is acyclic, there exists a schedule for determining vicinities as a function of proximity constraints only, in accordance with the invention, such that vicinities are computed in $O(n \cdot \log(n))$ time.

[0045] Proof 2: Given an acyclic graph of n nodes, the link $l=(n_i, n_j)$ can be located in the proximity graph that divides the acyclic graph into two subgraphs of sizes n' and $(n-n')$ nodes, respectively. Consider the subgraph containing n ,

where the vicinity of this node is modified as a function of n_j 's new vicinity, and that all the constraints within this subgraph have already been applied thereby making n_i the only node with a modified vicinity. Therefore, in accordance with Lemma 1 as set forth above, only one intersection need be performed to update each of n_i 's neighboring nodes in the subgraph. On a recursive basis, all the nodes in the subgraph can be updated in n' intersections, where n' is the number of nodes in such subgraph. Therefore, the run time of these operations is given by the following: $T(n)=T(n')+(T(n-n')+(n-n'))$. Assuming that $n'=n/2$, $T(N)$ can be determined on a recursive basis as: $T(n)=n \cdot \log(n)$.

[0046] The foregoing Detailed Description is to be understood as being in every respect illustrative and exemplary, but not restrictive, and the scope of the invention disclosed herein is not to be determined from the Detailed Description, but rather from the claims as interpreted according to the full breadth permitted by the patent laws. It is to be understood that the embodiments shown and described herein are only illustrative of the principles of the present invention and that various modifications may be implemented by those skilled in the art without departing from the scope and spirit of the invention.

We claim:

1. A method for determining a location of a node N_i in a communications network, the communications network having a plurality of nodes, the method comprising the steps of:

initializing each node of the plurality of nodes with an initial location, the node N_i and a node N_j being part of the plurality of nodes, and the node N_i having a vicinity V_i and the node N_j having a vicinity V_j ;

updating, in response the node N_i receiving a communication of the vicinity V_j , the vicinity V_i as a function of the vicinity V_j and a distance R , where R is the distance between the node N_i and node N_j ; and

broadcasting the updated vicinity V_i to the plurality of nodes as the location of the node N_i in the communications network.

2. The method of claim 1 wherein the function for the updating the vicinity V_i is defined as an intersection of (i) a first set of points associated with the vicinity V_i ; with (ii) a second set of points associated with the vicinity V_j and any point within the distance R of any point in the vicinity V_j .

3. The method of claim 2 wherein the node N_i is a floating node and the node N_j is a GPS node.

4. The method of claim 3 wherein the vicinity V_i is a subset of points in a region of the communications network that contains an actual location of the node N_i .

5. The method of claim 2 wherein the plurality of nodes includes only GPS nodes.

6. The method of claim 2 wherein the communications network is an ad hoc network.

7. A method for determining a location of a node N_i in a communications network, the communications network having a plurality of nodes, each of the nodes having a vicinity, the method comprising the steps of:

initializing each node of the plurality of nodes with an initial location, the node N_i and a node N_j being part of the plurality of nodes, and the node N_i having a vicinity V_i and the node N_j having a vicinity V_j ;

receiving, at the node N_i , a communication of the vicinity V_j ;

determining whether the node N_i and the node N_j can communicate with each other and

- (i) if so, updating the vicinity V_i as a function of the vicinity V_j and a distance $R1$, where $R1$ is the distance between the node N_i and node N_j , and the function for the updating the vicinity V_i is defined as an intersection of (a) a first set of points associated with the vicinity V_j ; with (b) a second set of points associated with the vicinity V_j and any point within the distance $R1$ of any point in the vicinity V_j ; and

broadcasting the updated vicinity V_i to the plurality of nodes as the location of the node N_i in the communications network; or

- (ii) if not, updating the vicinity V_i as a function of the vicinity V_j and a distance $R2$, where $R2$ is a maximum distance range (mdr), and the function for the updating the vicinity V_i is defined by removing a first set of points associated with the vicinity V_j from a second set of points associated with the vicinity V_j ; and

broadcasting the updated vicinity V_i to the plurality of nodes as the location of the node N_i in the commu-

nications network together with the vicinity of each of the other nodes in the plurality of nodes.

8. The method of claim 7 wherein the node N_i is a floating node and the node N_j is a GPS node.

9. The method of claim 7 wherein the vicinity associated with each of the node is a subset of points in a region of the communications network that contains an actual location of the node.

10. The method of claim 9 wherein the communications network is a mobile network.

11. The method of claim 8 wherein the first set of points is within a distance equal to the mdr of all points in the vicinity V_j .

12. The method of claim 9 wherein the subset of points of the vicinity is minimized by performing the respective updating operations on a recursive basis.

13. The method of claim 7 wherein the plurality of nodes includes only GPS nodes.

14. The method of claim 11 wherein the mdr is determined as a function of the floating node's transmission characteristics.

* * * * *